



Observation of short time-scale spectral emissions at millimeter wavelengths with the new CTS diagnostic on the FTU tokamak

Paper

Bruschi, A.; Alessi, E.; Bin, W.; D'Arcangelo, O.; Baiocchi, B.; Belli, F.; Calabro, G.; Casiraghi, I.; Cocilovo, V.; Figini, L.; Galperti, C.; Garavaglia, S.; Granucci, G.; Grosso, G.; Korsholm, Søren Bang; Lontano, M.; Lubyako, L.; Mazzotta, C.; Meller, V.; Del Moro, A.; Nielsen, Stefan Kragh; Orsitto, F.; Ramogida, G.; Rasmussen, Jesper; Ricci, D.; Pedersen, Morten Stejner; Tartari, U.

Published in:
Nuclear Fusion

Link to article, DOI:
[10.1088/1741-4326/aa6ce1](https://doi.org/10.1088/1741-4326/aa6ce1)

Publication date:
2017

Document Version
Early version, also known as pre-print

[Link back to DTU Orbit](#)

Citation (APA):
Bruschi, A., Alessi, E., Bin, W., D'Arcangelo, O., Baiocchi, B., Belli, F., ... Tartari, U. (2017). Observation of short time-scale spectral emissions at millimeter wavelengths with the new CTS diagnostic on the FTU tokamak: Paper. Nuclear Fusion, 57(7), [076004]. DOI: 10.1088/1741-4326/aa6ce1

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Observation of Short Time-Scale Spectral Emissions at Millimetre Wavelengths with the New CTS Diagnostic on the FTU Tokamak

A. Bruschi¹, E. Alessi¹, W. Bin¹, O. D'Arcangelo², F. Belli², G. Calabrò², I. Casiraghi³, V. Cocilovo², L. Figini¹, C. Galperti⁴, S. Garavaglia¹, G. Granucci¹, G. Grosso¹, S. B. Korsholm⁵, M. Lontano¹, V. Mellerà¹, A. Moro¹, S. K. Nielsen⁵, F. P. Orsitto⁶, M. S. Pedersen⁵, G. Ramogida², J. J. Rasmussen⁵, D. Ricci¹, and U. Tartari¹

¹*Istituto di Fisica del Plasma (IFP), Consiglio Nazionale delle Ricerche (CNR), 20125 Milan, Italy*

²*Associazione EURATOM-ENEA Unità Tecnica Fusione, Frascati, Italy*

³*Università degli Studi di Milano Bicocca, Milano, Italy*

⁴*Swiss Plasma Center (SPC), École polytechnique fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland*

⁵*Technical University of Denmark (DTU), Lyngby, Denmark*

⁶*Consorzio CREATE, 80125 Napoli, Italy*

Corresponding Author: A. Bruschi, bruschi@ifp.cnr.it

The collective Thomson scattering (CTS) diagnostic on FTU tokamak was renewed [1] for investigations on the excitation of parametric decay instabilities (PDI) by electron cyclotron (EC) beams in presence of magnetic islands and their effects on the EC absorption. Experiments were performed with a gyrotron probe (140 GHz, 400 kW) launched in symmetric and asymmetric configurations with respect to the equatorial plane, in different conditions of plasma density and magnetic field (with or without the EC resonance in the plasma), and with magnetic islands generated by Ne injection. The acquisition with a fast digitizer allowed observing spectral features with very high time and frequency resolution [2]. In the shots performed at 7.2 T, with the fundamental EC resonance out of the plasma region, a sequence of faint lines emitted with a fast temporal evolution have been observed in a range 0.5–1.1 GHz from the gyrotron frequency while at 4.7 T, with the resonance on the high field side of the plasma column, asynchronous “bursts” of continuous emissions were observed at a microsecond time scale.

In 2015 experiments were performed at 4.7 and 3.6 T, in this last case with the plasma between the first and the second EC harmonics. Different types of spectral features with a fast evolution were observed. Their correlation with magnetic probes and fast signals from the plasma has been investigated, to characterize the observations and exclude parasitic effects, as well as breakdown phenomena in front of the antennas. The variation in the stray radiation distribution in the vessel has been studied with the aid of a diffusive model, to characterize variations on the probe beam absorption associated to the observed phenomena. Further improvements of the diagnostic both in frequency band (up to ± 4.2 GHz from the probe) and with the addition of a second radiometer, will allow a clearer interpretation of the emissions.

References

[1] W. Bin, *et al.*, *Fusion Eng. Des.* **96–97**, 733–737 (2015).

[2] A. Bruschi, *et al.*, *Proc. 42nd EPS Conference on Plasma Physics* (2015).

Work carried out within the framework of the EUROfusion Consortium with funding from the Euratom research and training programme 2014–2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Observation of Short Time-scale Spectral Emissions at Millimeter Wavelengths with the New CTS Diagnostic on the FTU Tokamak

A. Bruschi¹, E. Alessi¹, W. Bin¹, O. D'Arcangelo², B. Baiocchi¹, F. Belli², G. Calabrò², I. Casiraghi³, V. Cocilovo², L. Figini¹, C. Galperti⁴, S. Garavaglia¹, G. Granucci¹, G. Grosso¹, S.B. Korsholm⁵, M. Lontano¹, L. Lubyako⁶, V. Melleri¹, A. Moro¹, S.K. Nielsen⁵, F. Orsitto⁷, M.S. Pedersen⁵, G. Ramogida², J. Rasmussen⁵, D. Ricci¹, U. Tartari¹ and FTU Team*

¹ Istituto di Fisica del Plasma - Consiglio Nazionale delle Ricerche, Milano, Italy

² ENEA C.R. Frascati, via E. Fermi 45, 00044 Frascati (Roma), Italy

⁵ Dipartimento di Fisica, Università degli Studi di Milano Bicocca, Milano, Italy

⁴ Swiss Plasma Center, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

⁵ Technical University of Denmark, Department of Physics, DK-2800 Kgs Lyngby, Denmark

⁶ Institute of Applied Physics, 46 Ulyanov st., Nizhny Novgorod, 603950, Russia

⁷ Consorzio CREATE, Università degli Studi di Napoli, Napoli, Italy

*See the appendix of G. Pucella et al., "Overview of the FTU Results", this Conference.

E-mail contact of main author: bruschi@ifp.cnr.it

Abstract. The Collective Thomson Scattering (CTS) diagnostic on FTU tokamak was renewed for investigations on the excitation of Parametric Decay Instabilities (PDI) by Electron Cyclotron (EC) beams in presence of magnetic islands and their effects on the EC absorption.

Experiments were performed launching a gyrotron probe beam (140 GHz, 400 kW) and receiving the CTS beam in symmetric and asymmetric configurations with respect to the equatorial plane, in different conditions of plasma density and magnetic field (with or without the EC resonance in the plasma), and with magnetic islands generated by Neon injection. The acquisition with a fast digitizer allowed observing spectral features with very high time and frequency resolution. In the shots performed at 7.2 T, with the fundamental EC resonance out of the plasma region, a sequence of faint lines emitted with a fast temporal evolution have been observed in a range 0.5-1.1 GHz from the gyrotron frequency while at 4.7 T, with the resonance on the high field side of the plasma column, asynchronous "bursts" of continuous emissions were observed at a microsecond time scale.

In 2015 and 2016 experiments were performed at 4.7 T and 3.6 T, in this last case with the plasma between the first and the second EC harmonics both lying outside the plasma volume. Different types of spectral features with a fast evolution were observed. Their correlation with magnetic probes and other fast signals from the plasma has been investigated, to characterize the observations and exclude parasitic effects, as well as breakdown phenomena in front of the antennas. The variation in the stray radiation distribution in the vessel has been studied with the aid of a diffusive model, to characterize variations on the probe beam absorption associated to the observed phenomena. The latest experiments, with a diagnostic improved both in frequency band (up to ± 4.2 GHz from the probe) and with the addition of a second radiometer, are allowing a clearer interpretation of the emissions.

1. Introduction

The Collective Thomson Scattering (CTS) diagnostic on the FTU tokamak, originally designed to investigate the CTS emission by thermal ions [1], was recently renewed [2, 3] for investigations on the possible excitation of low power threshold Parametric Decay Instabilities (PDI, see [4]) by ECRH beams in presence of magnetic islands, as observed in

TEXTOR [5], with the aim to add spectral evidences to the current interpretations [6], and study their possible effects on the absorption of powerful microwave beams used for Electron Cyclotron (EC) heating and Current Drive.

Experiments were performed with the same gyrotron probe (140 GHz, 400 kW) used for EC heating on FTU, launched and received from the equatorial FTU EC launcher [7, 8] in different geometrical configurations, plasma densities and magnetic fields (with or without the EC resonance in the plasma), and with Neon induced tearing modes. The dynamic of magnetic islands, with rotation frequencies of several kHz, required the use of a fast digitizer with acquisition frequency up to 12.5 GS/s, which allows observing new spectral features with very high time and frequency resolution [9]. The new diagnostic capabilities, the experimental setup and the experiments performed searching new evidences in the CTS spectra are detailed in the next sections, together with the work performed to interpret the results.

2. The improvements of the CTS diagnostic on FTU

Investigation on fast phenomena started in 2014, with a single receiving line, without polarization selection and with a single front-end receiving section including a notch filter, a mixer and a high-frequency Local Oscillator (LO), operating at 140 GHz and stabilized in frequency with a phase-locked loop driven by a synthesizer. At its output (in a ± 1.2 GHz bandwidth around the LO frequency) the conventional 32-channels radiometer (based on analog filter banks) was placed. In parallel, the new digitizer was connected directly to the Intermediate Frequency (IF) and used to monitor selected time intervals, obtaining spectra by direct Fast Fourier Transform (FFT) of the acquired IF signal.

For adding diagnostic capabilities, in the last two years different improvements were implemented. First, the received polarization selection, based on a universal polarizer made by two corrugated mirrors inserted into the last section of the quasi-optical receiving line. Second, the addition of another radiometer, similar to the first one, to implement a second radiometric channel, connected to the receiving line in parallel with the first by means of a beam-splitting wire-grid, in order to receive in the two radiometers the two orthogonal polarizations. As a third improvement, the bandwidth of the two radiometers has been extended to ± 4.2 GHz bandwidth around the LO frequency, substituting the amplifier sections of the two front-ends. Furthermore, a second notch filter has been added on one of the two receivers, in order to improve the protection of mixer by gyrotron stray radiation.

Further improvements are ongoing: a second separate receiving line, to allow direct comparison of signals with the ones acquired with the first line (as in ASDEX Upgrade [10]), is being designed. The receiving antenna, consisting of a corrugated waveguide with square section and of proper length to allow using that as a Remote Steering (RS) antenna, has been built and mounted on the equatorial plane of FTU port 8, the same used for EC and CTS antennas. Details of the improvements can be found in [11].

3. Experimental Setup

The experiments were performed with probe and receiving beams in symmetric and asymmetric configurations with respect to the equatorial plane of the tokamak, using the two symmetric antennas of the EC system operating with probe mirror in fixed position and receiving mirror swept toroidally during the pulse by an angle of a few degrees around the expected one for CTS beams overlapping, in order to find evidence of the actual beam crossing in the signals.

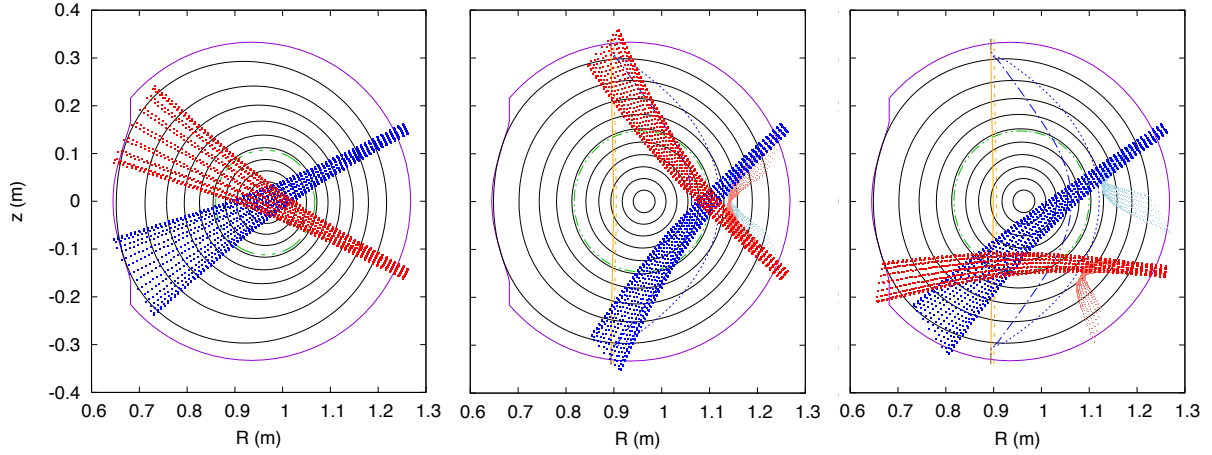


FIG. 1. Poloidal projections of O-mode polarized beams launched (red) and received (blue) with a toroidal angle $\beta=5^\circ$: (Left) $B_0=7.2$ T, crossing at the plasma magnetic axis. (Center) $B_0=4.7$ T, crossing at the $q=2$ surface on the LFS of the plasma mid-plane and (Right) crossing at the lower intersection between the $q=2$ rational surface and the cold first harmonic EC resonance. The $q=2$ rational surface is in green, the fundamental EC resonances in orange (solid=cold, dashed= Doppler-shifted), the Upper Hybrid layer and X-mode Right cut-off in blue (dash-dot, dotted respectively).

In Fig. 1 (from left to right) the poloidal projections of the probe and the receiving beams in the typical symmetric (7.2 T magnetic field, with crossing in the plasma magnetic axis and 4.7 T, with crossing on the $q=2$ magnetic surface) and asymmetric (4.7 T, with crossing on the EC resonance and the $q=2$ surface at the same time) are shown. All these configurations have been tested, typically in different plasma density conditions, with and without the presence of the $m:n=2:1$ magnetic islands. The main difference between the configurations is alternatively the presence, the absence and the position of the EC resonance with respect to the beam-crossing (scattering) volume. In the case of 7.2 T the first harmonic EC resonance is outside the plasma on the LFS, not interacting with the probe beam (unless in case of plasma formation in the port itself), while in the 4.7 T symmetric case the resonance acts as a dump of the probe radiation, reducing the level of stray power, in general disturbing the measurements. The 4.7 T asymmetric case has been studied in order to investigate the simultaneous effect of the injection of EC power on the resonance and the magnetic island, as is expected when EC power is used to stabilize NTM modes, as in recent experiments [12] and as foreseen in ITER [13] and DEMO [14].

4. Experimental Results

While in 2014 shots could be carried out at both the magnetic fields of 7.2 T and 4.7 T, in the two following years the high field of 7.2 T could not be performed. To realize a plasma scenario with both first and second harmonics EC resonances out of the plasma volume, shots at 3.6 T have been performed, with the first EC harmonic of the probe frequency on the high field side of the torus and the second EC harmonic on the low field side. The use of the fast digitizer showed the presence of very fast signals in the spectra, with characteristic times of the order of microseconds, that could not be resolved in time with the filter bank radiometer. For the interpretation of the spectra it is useful to recall that the heterodyne detector does not allow to distinguish the upper and lower bands with respect to the LO frequency, so that the two bands appear superimposed in the acquired spectrograms (frequency vs. time, with a color code for amplitude), and that the LO frequency is typically centered on the probe frequency, so that this last turns out to correspond to the same horizontal axis hidden by the

notch filter cut-off frequency band. Moreover, the input signal is chopped at 10 kHz for operating the background signal rejection on the radiometer, which is averaged then on the ms time scale. This chopping allows distinguishing in the FFT spectra the disturbances in the receiving chain from signals originating from the line. In the present setup it is not possible to distinguish spectral effects due to gyrotron sidebands received from the stray component which is not filtered by the notch. This will be further investigated when the second receiving line will be implemented.

While the study on the correlation of the emissions found in the spectra with the magnetic island is still ongoing (since not all the planned plasma configurations could be obtained, at the current time), a set of spectral features is here presented, mostly detectable only by choosing accurately both time and frequency resolutions for calculating the FFT.

In the following sections some spectral evidences are presented, not clearly correlated to magnetic islands and still without a definite explanation in terms of waves or phenomena.

4.1. Shots at 7.2T

In the shots performed at 7.2 T (possible only in 2014), with the fundamental EC resonance outside the plasma, sequences of faint lines have been observed in a range 0.5-1.1 GHz from the gyrotron frequency (Fig. 2, Left). When examined in detail, on a time scale strongly expanded, their extremely fast temporal evolution can be appreciated (Fig. 2, Right). The frequency difference with the probe tends to vary, increasing from 0.5 to 1.1 GHz in a few (2-5) microseconds. The phenomena associated to these lines are under study.

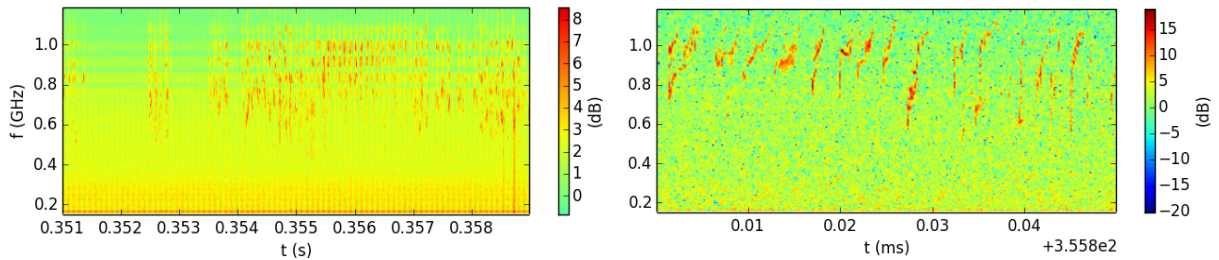


FIG. 2. Spectrum of the received radiation close to the gyrotron frequency for shot #38476 (scale in GHz, spectral amplitudes in dB, uncalibrated). Left: Fast emissions are visible in a frequency range between 0.5 and 1.1 GHz. Right: When resolved in microsecond time scale, measured starting from 0.3558 s, emissions appear as a sequence of faint lines emitted with a very fast temporal evolution.

4.2. Shots at 4.7 T

At 4.7 T, with the resonance on the high field side of the plasma column, in most of the shots either with or without magnetic islands detectable by magnetic probes, no emission disturbing the spectra and having a time behavior consistent with the rotation of the magnetic island has been found. On the other side, a continuous emission is sometimes observed in shots that do not present $m:n=2:1$ and $3:2$ tearing modes (at least, at a level detectable with the probes). Such emission, which cannot be resolved in spectral lines, appeared suddenly and disappeared after few milliseconds (Fig. 3, Left). It turns out to be composed temporally by "bursts" with a time scale of microseconds and asynchronous repetitions, with a finer temporal structure (Fig. 3, Right). This emission in the CTS spectra, at each corresponding spectral frequency, was anyway correlated in time with magnetic probe signal, showing a correlation at low level, possibly due to components at frequencies typically higher than the island rotation frequency.

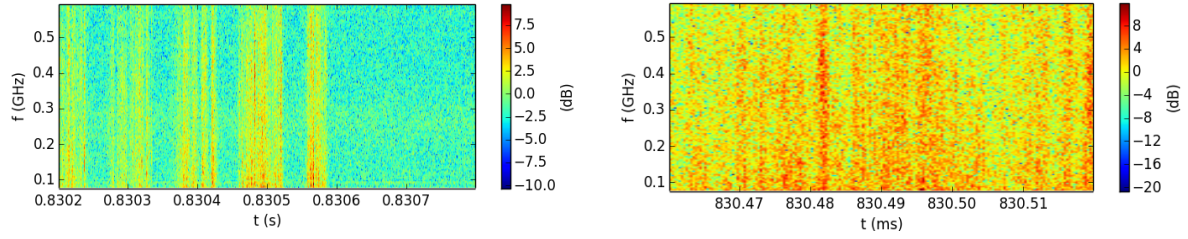


FIG. 3. Left: Spectrum of the received radiation close to the gyrotron frequency for shot #39003 (scale in hundreds of MHz, spectral amplitudes in dB, uncalibrated). Asynchronous sequence of bursts with broader continuum spectrum is detected up to 1 GHz from the gyrotron frequency. Right: Expanding the time scale around $t=830.46$ ms. there is no clear evidence of emissions in spectral lines.

4.3. Experiments in 2015

In the 2015 FTU campaign the experiments were performed at nominal toroidal magnetic field of 4.7 T and 3.6 T, respectively with the fundamental resonance in the plasma and with the plasma between the first and the second harmonic EC resonances. For easing the interpretation of the emissions, the LO frequency was significantly down-shifted, to visualize the gyrotron (probe) frequency 0.8 GHz far away from the notch filter stop band. This allows to better distinguish emissions lying above and below the probe frequency. In this condition the gyrotron line due to the stray radiation not fully absorbed by the notch filter is well visible in the spectrogram. Again, different types of spectral features with a fast evolution were observed. In particular, two of them are presently under deeper investigation: the first one consists of a rapid asynchronous sequence of bursts detected at frequency multiples of the (deuterium) ion cyclotron frequency, appearing above and below the gyrotron frequency and occurring in connection with an MHD activity which leads to plasma disruption (Fig. 4).

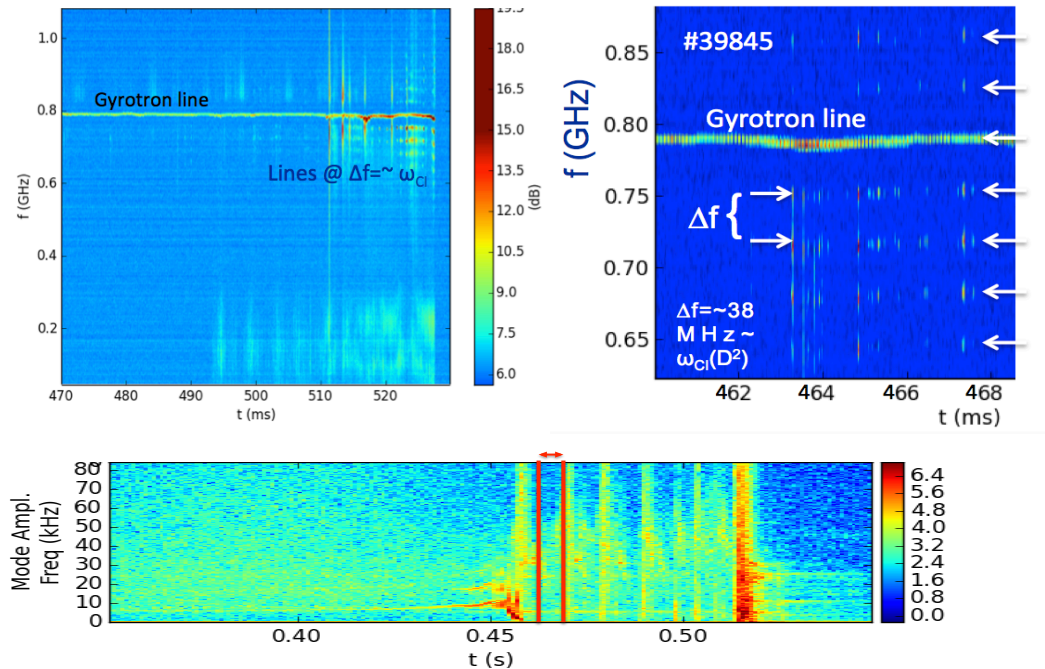


FIG. 4. Top Left: Spectrum of the received radiation in shot #39848 ($B_0=4.7$ T): the gyrotron line (highly attenuated) is visible 800 MHz away from the LO frequency, at 139.48 GHz. Top Right: The sequence of bursts emitted at frequency multiple of the deuteron ion cyclotron frequency, above and below the gyrotron line (shot #39845). Bottom: MHD spectrogram of shot #39845, showing an intense activity during the same time interval (marked by red vertical lines) of the top right figure.

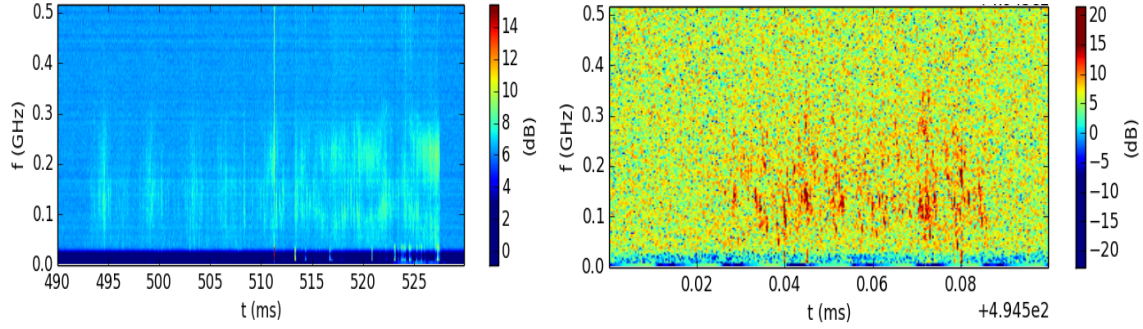


FIG. 5. Left: Lower-frequency band in spectrum of shot #39848: the emissions appear within ± 300 MHz from the LO frequency, corresponding to 0.5-1.1 GHz below the probe frequency. Right: When resolved in time around 494.5 ms, the same emission appears similar to the one observed at $B_0=7.2$ T.

The emissions visible in Fig. 3 (top right) seem to be linked to the MHD regime due to the effects of the Neon injection which is exploited to stimulate the $m:n=2:1$ magnetic island growth at the $q=2$ surface, typically triggering during the shot a strong activity associated with a particularly narrow plasma size and non-monotonic density (or temperature) profiles. The analysis of these regimes is complex, as the correlation of the timing of the bursts with the position (or sometimes even the existence) of significant perturbations of the magnetic equilibrium. For these reasons, even though the multiplicity and the frequency distance between the lines may be highly indicative of PDI process, an accurate interpretation of the phenomena occurring in these shots is not yet concluded and thus not presented in this work.

From the spectra shown in Fig. 4, additional lower-frequency emission bands are visible during the same time interval, as reported in Fig. 5 Left. These emissions, analyzed with a fine time-scale (Fig. 5, Right) reveal to be similar to the features observed at $B_0=7.2$ T, even though this time a higher noise level (due to higher stray power) make them less defined.

The second feature found in 2015 is a periodic emission at a frequency around 15 MHz from the probe frequency, with repetition rate of the same order the of the $m:n=2:1$ island rotation frequency (Fig. 6 Left). Correlation studies have been made to infer if the observed peaks were emitted in coincidence (or, at least, in a recognizable phase) with the transit of the island O-point in front of the CTS antenna, or maybe some multiple of the island rotation frequency, since the repetition rate of these emission sometimes is found significantly faster than the island rotation (Fig. 6, Right).

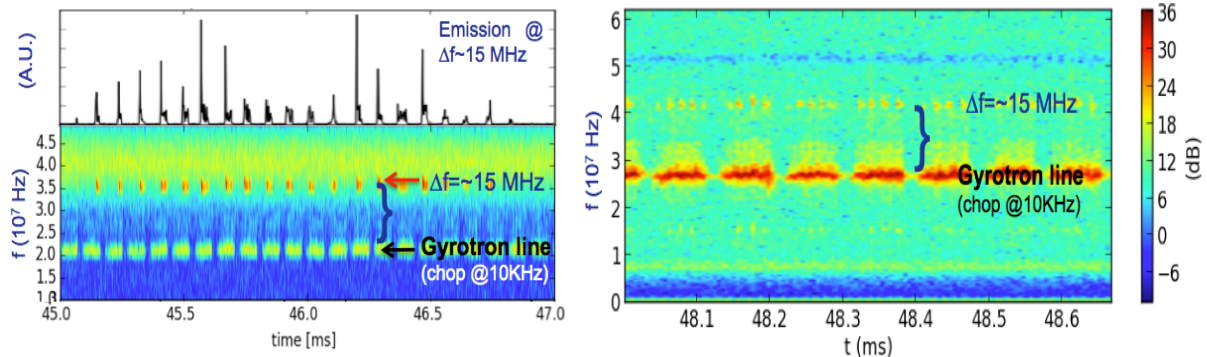


FIG. 6. Left: Periodic emission at frequency around 15 MHz from the gyrotron frequency: frequencies are shown with respect to the local oscillator frequency centered at 140.28 GHz. Right: The periodic emission at frequency around 15 MHz from the probe frequency is sometimes resolved in spots with a much higher (but regular) repetition rate, above and below the gyrotron frequency. Time is measured from the fast acquisition trigger, when probe frequency safely stabilizes in the notch filter stop band.

The study of the correlation of this line with the signal of magnetic probes required a preliminary work to isolate the information of the amplitude of this emission from the spectra, since the gyrotron frequency was not stable during pulse, varying by a few MHz, followed by the satellite emission at 15 MHz, as shown in Fig. 7 (top left). The effect of the uneven (sloping) notch filter attenuation on the two sides of the notch central frequency was taken into account to find the correct gyrotron "center" frequency, and therefore to correctly extract the amplitude of the 15 MHz sideband. Firstly, the correlation of the sideband amplitude with the gyrotron frequency or amplitude (that would suggest a possible origin of the line in the gyrotron emission spectrum) has been ruled out. Second, the spectrum of the sideband amplitude was analyzed. In order to enhance the fluctuations with amplitude higher than the background noise, at each timeslice where the FFT is calculated the power spectrum shown in Fig. 7 (top right) has been normalized by its average value, and maxima truncated at 10. It shows characteristic frequencies of emissions below 100 kHz, but at frequencies higher than the island rotation frequency, from 10 to 12 kHz in the same time interval, as obtained by the magnetic probe signal spectrum (Fig. 7, bottom). From the next campaigns, it will be possible to avoid the use of the chopping during operation with the radiometer. Lines around 10kHz and its harmonics, due to chopping, have been numerically cleaned in Figure 7 (top right). This further improvement should be helpful to determine the correlation between the oscillations observed in the 15MHz shifted emission and the island rotation frequency and its harmonics or other higher frequency magnetic perturbations.

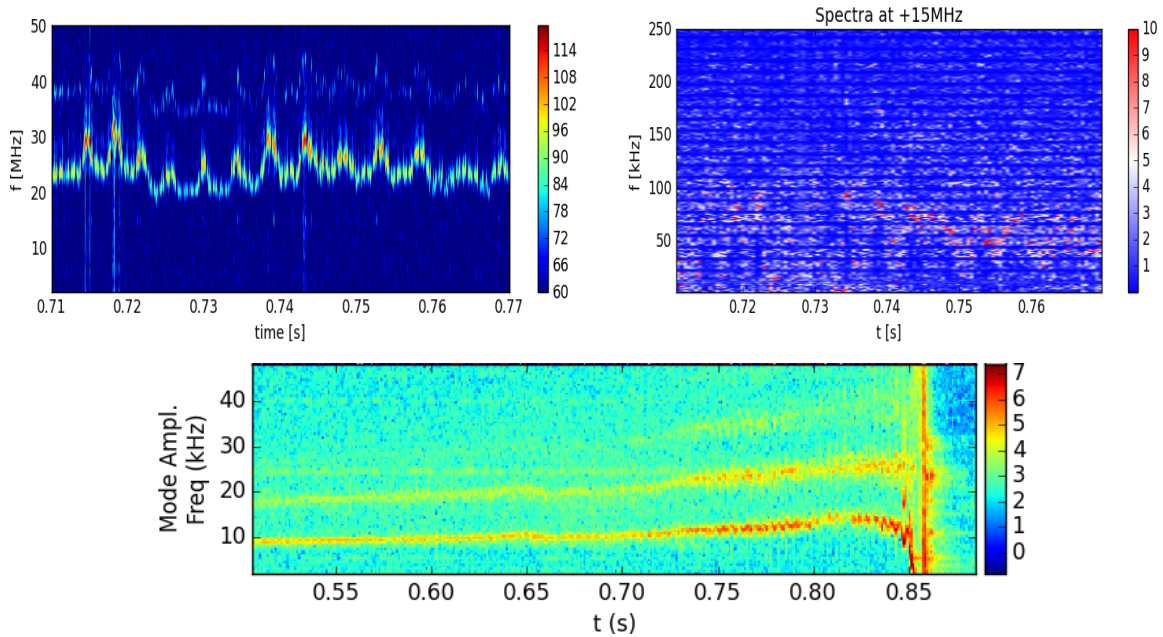


FIG. 7. Top Left: Varying Gyrotron frequency around 22 MHz from the LO during 60 ms acquisition in shot #39686. Spikes appear at a frequency around 37 MHz (around 15 MHz from the gyrotron frequency). Top Right: The frequency spectrum of the periodic emission at frequency around 15 MHz from the gyrotron show repetition at frequencies below 100 kHz. Bottom: Spectrum of a magnetic probe for shot #39686, showing an island rotating at 10 kHz.

5. Conclusions

The data of the experimental campaigns of 2015 showed also other phenomena at longer time scales, which deserve further attention and careful diagnostic calibration before conclusion can be drawn. Also the analysis of the data acquired during the recent FTU campaign (July 2016), not presented in this work, will provide additional indications to figure out correct interpretations of several phenomena. The improvements of the diagnostic in frequency band

(up to 4.2 GHz from the probe frequency), together with the addition of both a second radiometer and a second independent line of sight not crossing a scattering volume with the probe, will finally open the possibility to a clearer interpretation of the data.

Acknowledgment

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

- [1] TARTARI, U., et al., "Evolution of the millimeter-wave collective Thomson scattering system of the high-field tokamak Frascati Tokamak Upgrade", *Rev. Sci. Instrum.* **78** (2007) 043506.
- [2] BIN, W., et al., "The upgraded Collective Thomson Scattering diagnostics of FTU", *Fusion Eng. Des.* **96-97** (2015) 733-737.
- [3] BIN, W., et al., "First operations with the new Collective Thomson Scattering diagnostic on the Frascati Tokamak Upgrade device", *J. Instrum.* **10** (2015) P10007.
- [4] PORKOLAB, M., COHEN, B.I., "Parametric instabilities associated with intense electron cyclotron heating in the MTX tokamak", *Nucl. Fusion* **28** (1988) 239.
- [5] WESTERHOF, E., et al., "Strong Scattering of High Power Millimeter Waves in Tokamak Plasmas with Tearing Modes", *Phys. Rev. Lett.* **103** (2009) 125001.
- [6] GUSAKOV, E.Z., POPOV, A.Yu, "Low threshold parametric decay instabilities in ECRH experiments at toroidal devices", *Nucl. Fusion* **51** (2011) 073028.
- [7] BIN, W., et al., "Design of a new ECRH launcher for FTU tokamak", *Fusion Eng. Des.* **84** (2009) 451-456.
- [8] BRUSCHI, A., et al., "A new launcher for real-time ECRH experiments on FTU", *Fusion Sci. Technol.* **55** (2009) 94.
- [9] BRUSCHI, A., et al., "Experimental studies with the improved CTS diagnostics on FTU and evidences of scattered wave signals with short time-scale", *Proc. 42nd EPS Conference on Plasma Physics* (2015).
- [10] NIELSEN, S.K., et al., "Measurements of the fast-ion distribution function at ASDEX upgrade by collective Thomson scattering (CTS) using active and passive views", *Plasma Phys. Control. Fusion* **57** (2015) 035009.
- [11] BIN, W., et al., "Advances in the FTU collective Thomson scattering system", *Rev. Sci. Instrum.* **87** (2016) 11E507.
- [12] MARASCHEK, M., et al., "Enhancement of the stabilization efficiency of a neoclassical magnetic island by modulated electron cyclotron current drive in the ASDEX upgrade Tokamak", *Phys. Rev. Lett.* **98**, Issue 2 (2007) 025005.
- [13] HENDERSON, M.A., et al., "Overview of the ITER EC upper launcher", *Nucl. Fusion* **48**, Issue 5 (2008) 054013.
- [14] WENNINGER, R., et al., "Advances in the physics basis for the European DEMO design", *Nucl. Fusion* **55** (2015) 063003.